

Line-Strength Gradients in Cooling Flow Galaxies

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Abstract. We present new results on line-strength gradients in a sample of 18 brightest cluster galaxies (13 in clusters with cooling flows and 5 in clusters without). Here we focus on the study of the Mg_2 index and the 4000Å break (D_{4000}). We find that line-strength gradients vary markedly from galaxy to galaxy, depending both on the mass deposition rate and the presence or not of emission lines in the nuclear regions. Gradients are found to be flat, and even positive (i.e. bluer when going inwards), in the emission-line region of the cooling flow galaxies with emission lines. However, outside the region where emission lines are present, mean spectral gradients of brightest cluster galaxies, in clusters with and without cooling flows, are consistent with those observed in giant elliptical galaxies. In addition, and in agreement with previous studies, we confirm a correlation between central spectral indices and the mass deposition rates, although we find that cooling flow galaxies without emission lines do not follow this trend.

1. Introduction

The study of spectral absorption features provides a direct test of the possible presence of young stellar population in brightest cluster galaxies (BCG's) immersed in cooling flow clusters (Sarazin 1986). Cooling flows have been revealed in X-rays studies, but so far work in the optical has failed to produce substantial *direct* evidence for their presence (Fabian 1994). The mechanism(s) responsible for the connection, if any, between the emission line regions usually found at the centers of many cooling flow galaxies, the blue excess, and the cooling flow phenomenon itself remain unclear (Baum 1992, Fabian 1994, and references therein). Line-strength gradients are a powerful tool to investigate the radial distribution of stellar populations in galaxies. They could be a measurement of the amount of dissipation that occurred during the star formation phase in the galaxies (see González & Gorgas 1996 for a recent review on spectroscopic gradients in early-type galaxies). Typically, metallic line-strengths decrease outwards in elliptical galaxies, which has conventionally been interpreted as a decrement of metallicity with radius (Faber 1977). However, age effects may also play an important

role (Aragón, Gorgas & Rego 1987; Gorgas, Efstathiou & Aragón-Salamanca 1990; González 1993, Faber *et al.* 1995). The application of evolutionary population synthesis models can help to disentangle this degeneracy between age and metallicity (Worthey 1994). In this talk, we highlight results derived from an extension of the work presented in Cardiel, Gorgas & Aragón-Salamanca (1995) after the inclusion of extensive new spectroscopic data, obtained with the WHT.

2. Mg₂ and the 4000Å break

We have measured line-strength gradients in a sample of 18 galaxies (13 in clusters with cooling flows and 5 in clusters without). We concentrate here on the study of the Mg₂ index and the 4000Å break. Both spectral features are good indicators of changes in the stellar populations of early-type galaxies and can be measured in spectra with relatively low signal-to-noise ratios. This last property is important when trying to obtain reliable measurements out to $r \sim r_e$, where the surface brightness of a typical BCG is only a few per cent of the sky brightness. In Figure 1 we show 4000Å gradients for six galaxies in our sample.

Mg₂ has been extensively studied by Gorgas *et al.* (1993) and Worthey *et al.* (1994), who derived empirical fitting functions to model the behavior of this spectral feature with the stellar atmospheric parameters. D₄₀₀₀ is quite sensitive to the temperature of the main-sequence turn-off (Hamilton 1985, Dressler & Shectman 1987), although its dependence on metallicity is not negligible (Worthey 1994). The corresponding fitting functions for this feature are under construction (Gorgas & Cardiel 1996). When these empirical calibrations are incorporated into stellar population models (Worthey 1994, Charlot & Bruzual 1996), we will be able to interpret the observed line-strengths in terms of mean age and metallicity of the stellar populations.

It is important to note that the Balmer-line indices (H β , H γ_A , H δ_A , or H γ_{HR}), widely used as age discriminators for stellar population in elliptical galaxies (González 1993, Rose 1994, Faber *et al.* 1995, Jones & Worthey 1995), are useless for such purpose here since, in many cases, prominent emission prevents the observation of the underlying absorption features in cooling flow galaxies. Moreover, in order to get reliable line indices, emission lines within the Mg₂ and D₄₀₀₀ bandpasses (e.g. [NeIII] λ 3869, [SII] $\lambda\lambda$ 4069,4076, H δ , [OIII] λ 4959, [NI] λ 5200) must be carefully removed (see details in Cardiel, Gorgas & Aragón-Salamanca 1996) prior to any measurement.

3. Results

Full details of the new galaxy sample and measurements will be given in a forthcoming paper (Cardiel, *et al.* 1996). We summarize here the main results which emerge from this study.

- Central¹ Mg₂ and D₄₀₀₀ measurements in cooling flow galaxies *with emission lines* are well correlated with mass deposition rate, in the sense

¹Inside a fixed aperture of 4 arcsec projected at the distance of the Coma cluster, i.e. 1.8 kpc for $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

Figure 1. D_{4000} gradients for six galaxies in our sample ($H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ assumed). The thick horizontal solid line (upper left) indicates the spatial extension of the emission lines (when present). Mass deposition rates in M_\odot/yr (Edge *et al.* 1992) are given in the upper right corner. Filled circles and stars refer to different sides of the galaxies. Open symbols correspond to secondary nuclei. Lines represent error-weighted least-squares fits, excluding data with $r < 1.5 \text{ arcsec}$ (affected by seeing) and secondary nuclei.

that both indices decrease —suggesting the presence of a young stellar population— when the mass flow increases. Similar correlations of central blue colors and spectral features with mass rates have been previously reported by different authors: Johnstone, Fabian & Nulsen (1987) found a correlation between the D_{4000} and the mass flow rate \dot{M}_V within their spectrograph slit; McNamara & O’Connell (1989) presented a correlation between their δUB (which is well correlated with D_{4000}) and the normalized rate of mass drop out in the nucleus per unit luminosity $(\beta/\beta_0)_{\text{nuc}}$; finally, McNamara & O’Connell (1992) showed that the strength and extend of bluer central colors are more prominent for central galaxies in clusters with high mass accretion rates.

- Interestingly, nuclear indices in the cooling flow galaxies of our sample *without* emission lines (e.g. A 644, A 2142) *do not* follow this correlation with \dot{M} , which is also the case for A 2029 in the $\delta UB-(\beta/\beta_0)_{\text{nuc}}$ diagram from McNamara & O’Connell (1989). The central line-strengths of BCG’s in both clusters without cooling flows and cooling flow galaxies without emission lines are consistent with the values observed in giant ellipticals.
- The central line-strengths of elliptical galaxies define a relatively narrow trend in the D_{4000} – Mg_2 plane (Kimble, Davidsen & Sandage 1989). However, central Mg_2 and D_{4000} measurements in cooling flow galaxies exhibit a clear correlation (see Figure 5 in Cardiel *et al.* 1995) which departs from the locus where giant elliptical galaxies are found. The inclusion of new galaxies in our sample has revealed that there is a clear dichotomy in the way cooling flow galaxies with emission lines populate this plane. Galaxies with central emission-line nebulae of class II (following the scheme of Heckman *et al.* 1989), e.g. PKS 9745–191, Hydra A, A 1795, A 2597, exhibit the largest departures from the elliptical galaxy region in the D_{4000} – Mg_2 diagram. When compared with stellar population model predictions this provides strong evidence for recent star formation in these galaxies.
- Although line-strength gradients are usually found to be linear with $\log(r)$ in elliptical galaxies (González & Gorgas 1996), Mg_2 and D_{4000} gradients in some cooling flow galaxies exhibit a clear slope change at intermediate radii (Cardiel *et al.* 1995). With the inclusion of new spectroscopic data, we find that this change of slope is only evident for galaxies with emission lines (Figure 1).
- Cooling flow galaxies *with emission lines* exhibit flat and even positive gradients in the region where the emission is detected. In fact, these inner gradients seem to be correlated with mass deposition rate (i.e., more positive with increasing \dot{M} ; see Figure 2). In the outer parts of these galaxies, where emission is not observed, the derived mean line-strength gradients are consistent with those in elliptical galaxies.
- Mean gradients in galaxies with cooling flows but *without emission lines* are similar to those in galaxies without cooling flows and those in elliptical galaxies (Figure 3).

Figure 2. D_{4000} and Mg_2 gradients for the galaxies of our sample versus mass deposition rate (in M_{\odot}/yr). Open symbols correspond to inner gradients (i.e. in the emission line region) of cooling flow galaxies, whilst closed circles stand for galaxies without cooling flows and cooling flow galaxies without emission lines.

Figure 3. Comparison of mean D_{4000} and Mg_2 gradients for normal ellipticals (E's), brightest cluster galaxies without cooling flows (BCG's No CF), cooling flow galaxies without emission lines (CFG's No EL), and cooling flow galaxies with emission lines (CFG's EL) in the inner (i.e. emission line) and outer (out from the emission line) regions. Error bars indicate the formal errors in the mean values.

4. Discussion

• **Blue excess and emission lines.** Previous work has shown that in the central parts of massive cooling flows the emission line luminosity correlates with the blue light excess (Johnstone *et al.* 1987, Allen *et al.* 1992, Crawford & Fabian 1993, Crawford *et al.* 1995). In addition, the emission line flux is co-spatial with the excess blue light (e.g. Romanishin 1987, Hansen, Jørgensen & Nørgaard-Nielsen 1995). Our Mg_2 and D_{4000} gradients confirm that the spatial extent of the excess blue light is very similar to the emission line region (Figure 1). These results indicate that, very likely, both processes are physically related. However this is a question of open debate (see discussion in Baum 1992, Fabian 1994, and references therein). Using blue optical spectra and IUE data, Crawford & Fabian (1993) showed that the spectrum of the excess blue light is consistent with both star formation and a power-law spectrum. Allen (1995), using simple stellar population models, suggested that young stars are responsible of the spatially extended excess UV/blue continua. Our analysis of central Mg_2 and D_{4000} measurements in a sample of BCG's with and without cooling flows using Bruzual & Charlot (1993) stellar population models suggests the observed correlation between both indices can be reproduced with star formation at a constant rate over the last few Gyrs (Cardiel *et al.* 1995). However, further work in the stellar population modelling is still needed to definitely rule out a power-law spectrum as the origin of the blue excess.

• **The cooling flow connection.** The presence of emission lines must be in some way related to cooling flows since $H\beta$ (Johnstone *et al.* 1987) and $H\alpha$ luminosity (Heckman *et al.* 1989) are correlated with mass deposition rate. However, considering the high scatter in line luminosities for a given \dot{M} , the relationship does not seem to be a simple one (Baum 1992). Whichever mechanism is responsible for the dilution of the measured line-strength indices (star formation, scattering of nuclear light, etc.), the correlations of the mass deposition rate with central indices and line-strength gradients in the emission line regions add further weight to the idea of a link between the blue excess and the cooling flow phenomenon. Nevertheless, as Crawford & Fabian (1993) pointed out, the fact that there are central galaxies (e.g. A 644, A 2029) in clusters with high \dot{M} but without blue excess suggests that the cooling flow alone cannot be responsible for the blue light. These authors also noted the existence of strong cooling flow galaxies, with (e.g. A 478) and without (e.g. A 2029) emission-line nebulae, which apparently did not exhibit a blue continuum excess. However, our D_{4000} gradient in the central galaxy of A 478 (Figure 1) does exhibit a clear positive behaviour (i.e. blue excess) in the emission line region. A larger sample is needed to test whether there are any cooling flow galaxies with line-emission nebulae which do not exhibit blue excess, and vice versa.

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